RESEARCH DEPARTMENT

MEASUREMENTS ON LOADED BUILDING-BOARD PANEL SOUND ABSORBERS

Report No. B-064

(1956/18)

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SUMMARY

Measurements have been made of the absorption coefficient of resonant absorbers consisting of soft building-board panels loaded with steel weights. The results do not substantiate the claims made by Continental workers because the mode of action appears to be completely different from that postulated in a recent paper.

A possible explanation of the experimental results is suggested and some measure of agreement with theory found.

1. INTRODUCTION.

A recent paper by Lauber[1] described resonant absorbers similar to those due to von Braunmühl and Westphal consisting of panels of soft building-board mounted on wooden frames; steel weights were bolted to the centre of the panels and a blanket of glasswool could be mounted behind the panel to provide damping.

Peaks in the absorption coefficient were reported at frequencies between 80 c/s and 200 c/s according to the dimensions of the panel and the load applied. Thus a peak was obtained at 86 c/s with a panel 79 cm × 104 cm, a frame 21 cm deep and a load of 2·5 kg at the centre; removal of the load raised the peak frequency to 190 c/s. Some agreement was claimed between the experimentally measured resonance frequencies and the values calculated on the basis of a formula also used by Kurtze[2], assuming that the weight and panel vibrate in a simple manner against the spring stiffness of the enclosed air.

Since these absorbers are coming into widespread use in Switzerland and elsewhere[3], it was decided that an independent investigation should be made to supplement the published results. These absorbers appeared inferior, in respect of maximum absorption coefficient and bandwidth, to the membrane absorbers extensively used in B.B.C. studios, but might have applications as narrow band absorbers in special circumstances. Building-board panels of approximately the same size were therefore mounted as described and the absorption characteristics were determined, initially by the reverberation room method and later in an impedance tube.

2. EXPERIMENTAL WORK.

2.1. Reverberation Room Measurements.

2.1.1. Method.

Measurements were made in a reverberation room of volume 3280 ft^3 (90 m^3) with a reverberation time of approximately 8 sec at 90 c/s falling to 1·1 sec at 8 kc/s. At the lower frequencies short pulses of tone, of duration 3 cycles each, were used as the exciting sound; they were generated by a constant bandwidth pulse generator[4] and gave an effective bandwidth of 1/3 octave around each test frequency. Above 2 kc/s, however, longer pulses of warbled tone were used since insufficient energy was supplied by the short pulses, and the warble tone measurements were in some instances extended over the whole frequency range as a check of the agreement between the two sources of sound.

A loudspeaker in a corner of the room was used as the source. The sound in the room was picked up by a moving coil microphone, amplified to a suitable level, passed through octave band-pass filters and applied to a logarithmic amplifier. The output from the logarithmic amplifier was displayed on an oscilloscope and the reverberation time was read directly by means of a goniometer mounted on the oscilloscope as described in a previous report[5]. Results from ten microphone positions were averaged at each frequency.

Four frames, each 6 ft × 4 ft (1·8 m × 1·2 m) and divided into two sections 3 ft × 4 ft (0·9 m × 1·2 m) as shown in Fig. 1, were used for measurements. Each carried a sheet of building-board ½ in. (1·2 cm) thick, nailed round its edges and across the dividing line. Damping in the form of 1 in. (2·5 cm) rockwool was fastened behind, but not touching, the building-board panel which was backed by an air space 3½ in. (9 cm) deep. Alternative weights of 2·5 and 1·0 kg were used as in Reference 1.

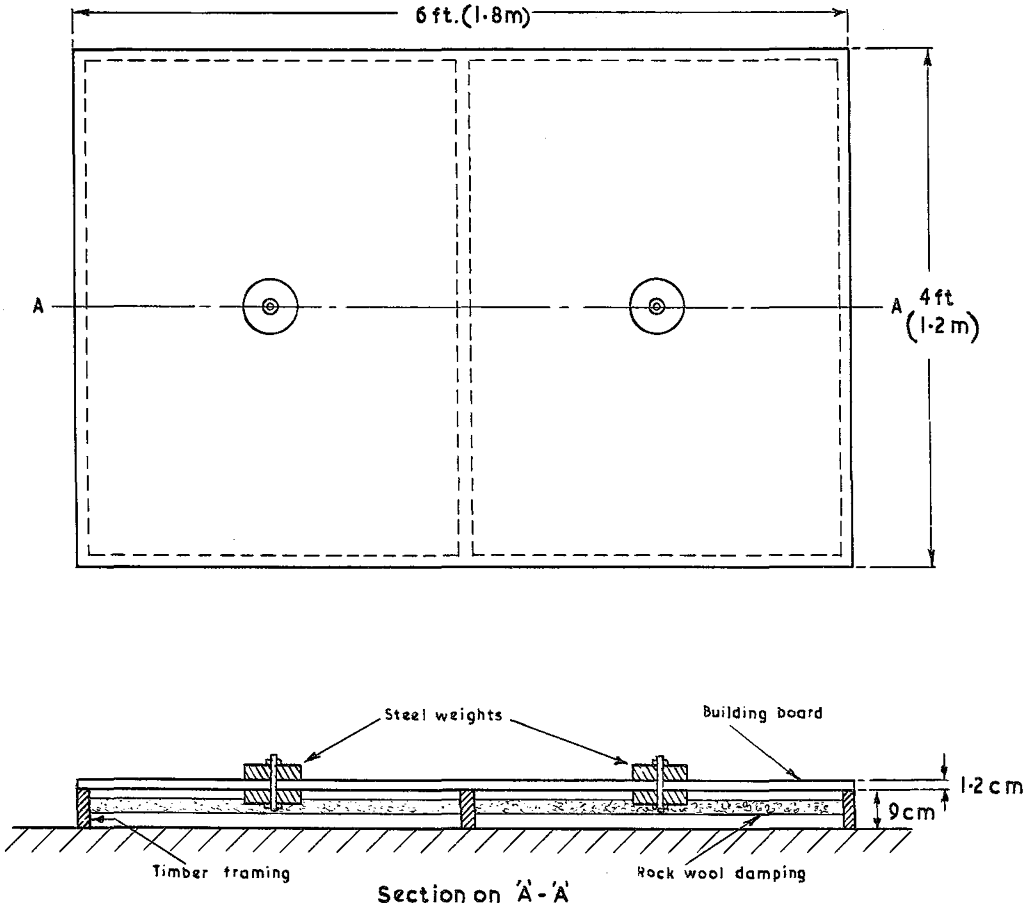

Fig. 1 - Building-board panel resonator

Total absorption values were obtained from the measured reverberation times by application of Eyring's formula:

$$T = \frac{0{\cdot}049\,V}{-S\,\log_e\,(1-\bar{\alpha})_s}$$

where T = reverberation time
S = area
$\bar{\alpha}$ = average absorption coefficient

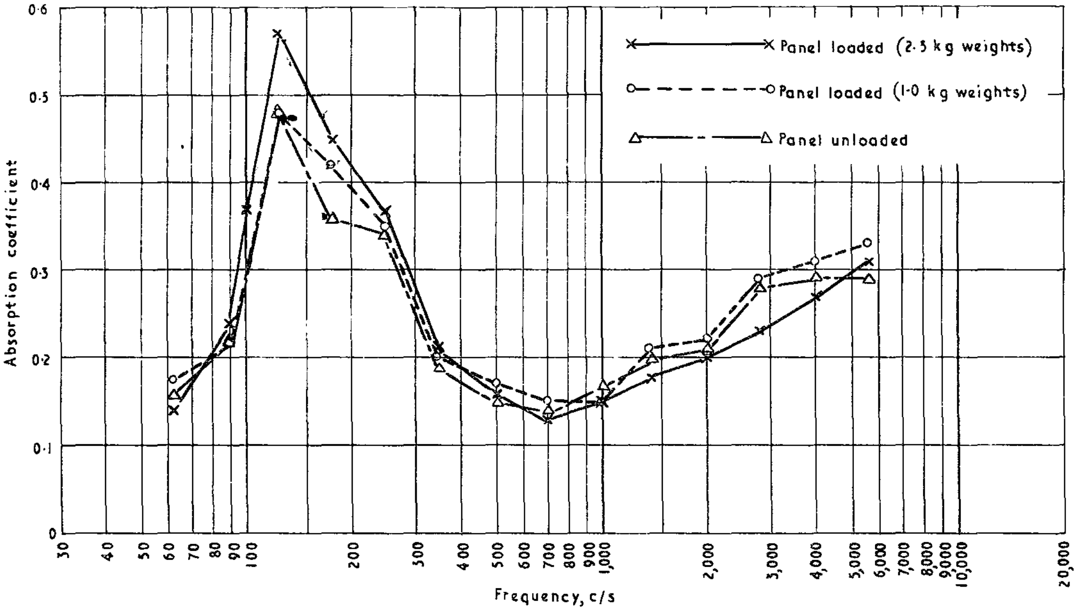

Fig. 2 - Reverberation room measurement

2.1.2. Results.

The results showed a peak in the absorption coefficient at about 120 c/s, which did not move with variation of the load, (see Fig. 2) although a small increase in the peak height was found with the heavier weights.

It was thought unlikely that a weight of 2·5 kg would oscillate at such a high frequency when suspended at the centre of so compliant a panel. Static depression measurements indicated a fundamental frequency in the region of 10 c/s which was confirmed approximately by observation on shock excitation of the panel. It was therefore clear that the panel and weight were not vibrating in a simple mode and experiments were carried out with an accelerometer attached to different parts of the panel (Fig. 3). The panel was driven by approximately plane waves at 125 c/s, corresponding to the frequency of the absorption peak, and the excitation determined along lines through the centre of the weight under the different conditions of loading. The results show, as was expected, that the weight constrains the centre of the panel, wholly or partially, while the remainder of the panel vibrates. Thus the 2·5 kg weight reduces the vibration at the centre to the same extent as the frame to which the building-board is nailed and the 1·0 kg weight also reduces the excitation at the

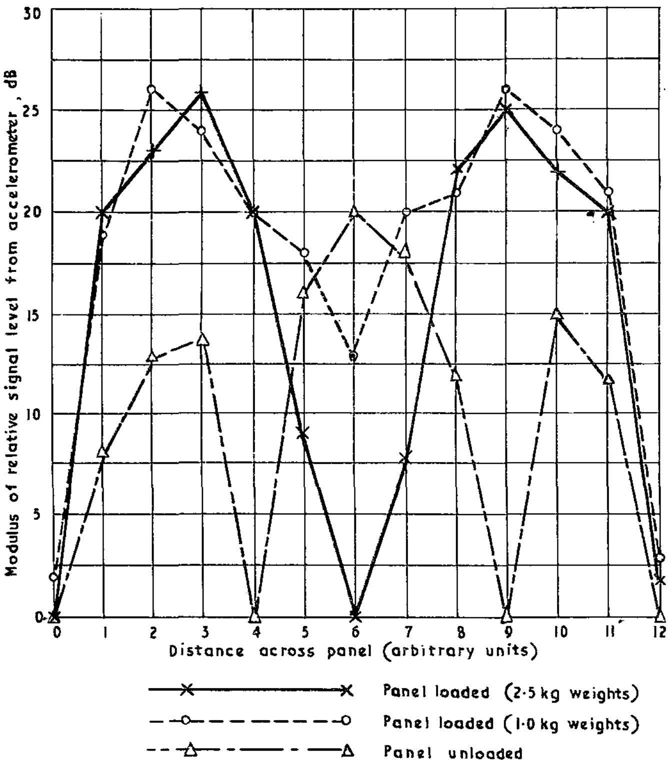

Fig. 3 - Distribution of vibration amplitude across panel

centre but to a lesser degree. With the unloaded panel, however, a peak is found at the centre and there is a sharp nodal ring round the centre with the panel vibrating strongly on both sides of it.

The inside dimensions of the panel were 118 cm × 88 cm and the depth of air space 9·3 cm. The weight of the building-board was approximately 3·23 kg/m². If we use the simple formula quoted by Lauber,

$$f_0 = \frac{1}{2\pi}\sqrt{\frac{1}{MF}}$$

where M = mass of the panel

F = compliance of the air $= \dfrac{V}{\rho_0 c^2}$

V = volume of air enclosed

ρ_0 = normal density of the air

c = velocity of sound

the calculated resonance frequency is 109 c/s. This agrees with the diagrams given in his paper which show a resonance frequency of about 107 c/s.

These calculated results are rather lower than the measured values, partly due to the fact that the stiffness of the board is neglected. Kurtze's paper suggests a stiffness correction of 30% to 40% for 40 cm square acoustic tiles, though these would be expected to have a greater inherent stiffness than the building-board.

It is possible to calculate a value for the resonance frequency of the unloaded panel assuming that it vibrates as a stiffness controlled circular plate. Observation of a nodal ring in the accelerometer measurements shows a similarity to a circular plate vibrating in its first overtone.

The formula for the resonance frequency as given in Reference 6 is:

$$f_{01} = 0{\cdot}93\,\frac{h}{a^2}\sqrt{\frac{Y}{\rho(1-\sigma^2)}}$$

where h = half-thickness of plate

a = radius of equivalent circular panel $= \sqrt{\dfrac{\text{area}}{\pi}}$

Y = Young's modulus of building-board

ρ = density of building-board

σ = Poisson's ratio of building-board

Young's modulus was found, from measurements on a strip of the material, to be 2·04 × 10^9 dynes/cm^2. As the value of σ does not affect the calculated value of f_{01} very critically, an assumed value of zero was taken as a good approximation for a fibrous material of this type.

This formula gives a value of 15 c/s for the fundamental resonance frequency and 58 c/s for the first overtone (f_{02}) of the unloaded panel controlled only by its inherent stiffness.

A further value for this resonance frequency can be obtained from the measured peak absorption frequency of the panel and the calculated value of the compliance of the air enclosed behind it. Such a calculation gives a value of 59 c/s for the stiffness controlled resonance.

Considering the case of a 2·5 kg weight supported on the panel and the whole vibrating in its fundamental mode, we obtain a value of 11·5 c/s for the calculated resonance frequency; this is in good agreement with the value derived from measurements of the static stiffness taken previously.

These results and conclusions are irreconcilable with those of Lauber and it was felt that this was an unsatisfactory point at which to leave the work. Duct measurements were therefore carried out in an attempt to determine whether the method of measurement affected the mode of operation.

2.2. Duct Measurements.

2.2.1. Method.

The duct at Kingswood Warren used for this work is of brick construction with a top of concrete slabs which can be removed. The dimensions of the duct (0·6 m × 0·75 m) are sufficiently small for the sound field up to a limiting frequency of 300 c/s to be represented by two plane waves travelling in opposite directions. A microphone on a trolley can be moved along the duct by means of a cable to measure the signal level at different points, and hence determine the standing wave ratio. To calculate the absorption coefficient a measurement of the ratio of p_{max}/p_{min} at the first two minima away from the panel was required[7]. This measurement was obtained directly in decibels from an amplifier detector, using the equipment shown in the block schematic of Fig. 4.

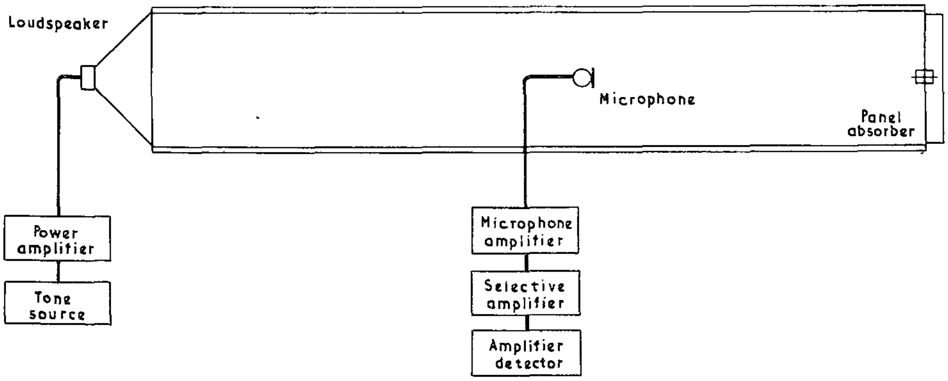

Fig. 4 - Equipment used in duct measurements — block schematic diagram

2.2.2. Results.

The results are shown in Fig. 5. It may be seen that there are apparently several peaks in the absorption coefficient in the region covered, whereas calculations would lead one to expect a single resonance at 109 c/s. There is no significant shift of the curve on change of loading of the panel and it is clear therefore that the panel and weight were not vibrating in the simple manner assumed in Section 1 above.

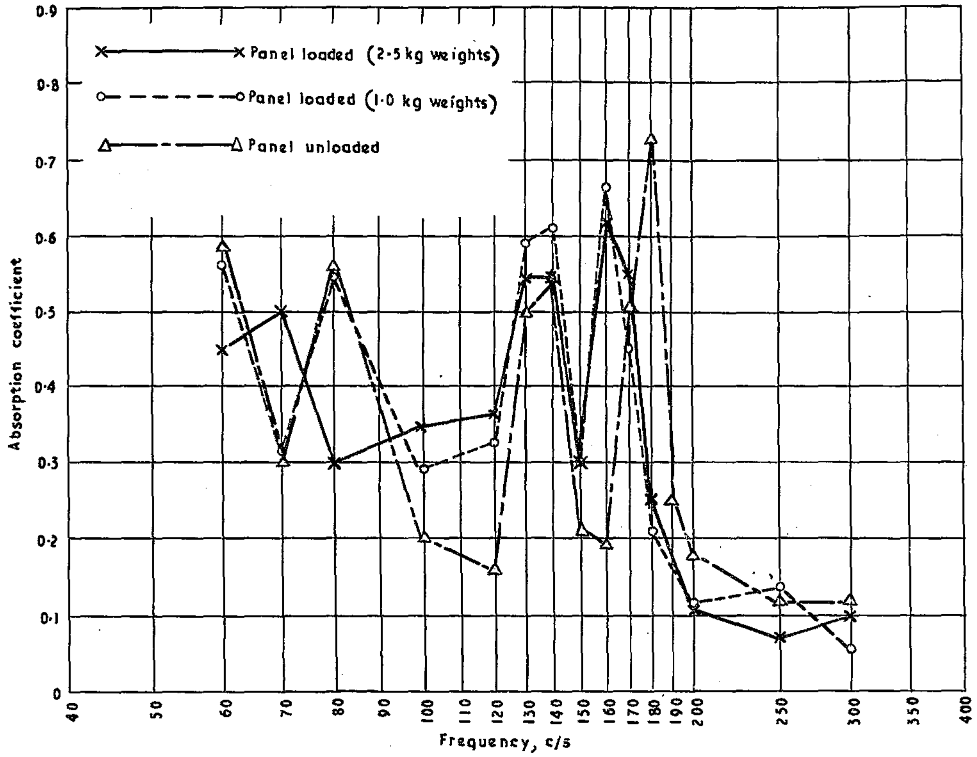

Fig. 5 - Duct measurements

A large section of the rear of the resonator was removed and it was found that the peak normally at 160 c/s shifted in relation to the remainder of the curve. This then would appear to be the peak controlled by the air stiffness. By taking this experimental result and the value of 109 c/s derived from the known depth of the absorber, the resonance frequency of vibrations controlled purely by the stiffness of the building-board can be calculated; the value so determined is 117 c/s. If now the stiffness is assumed to be the same as in the first experiment and the smaller mass vibrating taken into account, then a value of about 102 c/s is indicated which is in agreement with the value found here. A further value can be calculated as in the previous case using the formula for a stiffness controlled plate vibrating in its first overtone; this gives f_{02} = 138 c/s. Complete agreement of these figures cannot be expected since the tightness of clamping of the edges of the board will influence greatly the stiffness obtained and since the value calculated from peak absorption frequency and air compliance depends to a considerable extent on the value taken for the peak absorption frequency.

3. DISCUSSION OF RESULTS.

It is not possible to reconcile these results with those given by Lauber. It appears that under the conditions of these measurements the weight used to load the panel does not vibrate and no shift of the resonance frequency would be expected by changing the mass of the weight.

In Lauber's results the calculated values given in the paper are in general about 30 c/s lower than the measured values for the loaded panels, a discrepancy which can be explained by the neglect of the stiffness of the board. When, however, the results for the unloaded panels are considered there is no agreement between the experimental results and those calculated from his figures.

If, further, values for the resonance frequency of his panels are calculated on the assumption that the weight does not vibrate, in all but one case better agreement is obtained with the experimental results than in his original calculations.

In Fig. 6 graphs are given comparing the absorption characteristics of building-board panel absorbers with the B.B.C. roofing felt membrane absorbers. Curves (a) and (b) are taken from Reference 1 and curves (c) and (d) measured by the author. Curve (a) is a Swiss P.T.T. panel absorber loaded with a 1·0 kg weight and measured in a duct; (b) is the only reverberation room measurement reported and is for a similar panel loaded with 2·23 kg. (The break in the curve between 200 and 300 c/s is shown in the original paper but is not explained.) Curve (c) is for a building-board panel absorber loaded with a 1 kg weight and measured in the reverberation room. Curve (d) is a B.B.C. membrane absorber of similar depth, also measured in a reverberation room. All these types are damped with glass- or rock-wool.

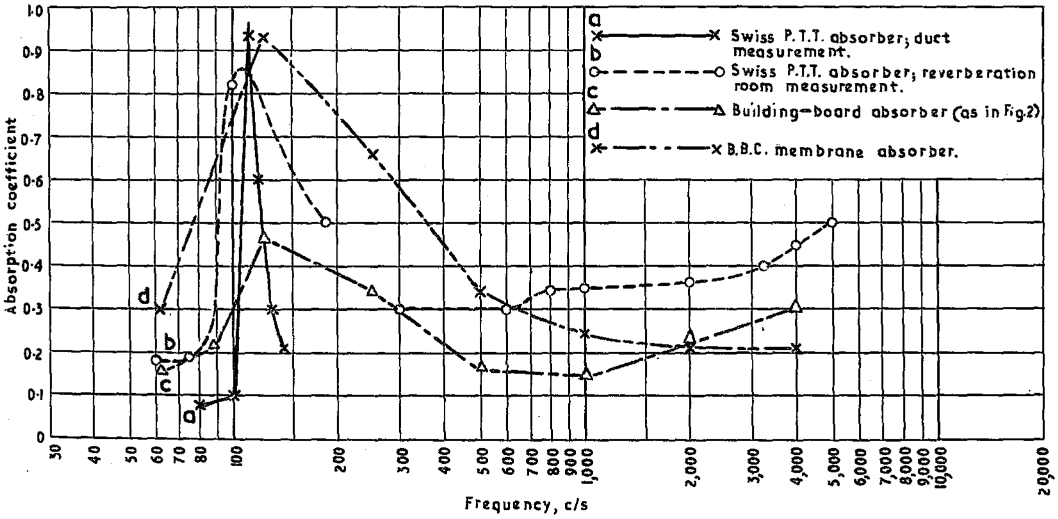

Fig. 6 - Comparison of building-board and membrane absorbers

It will be seen that the membrane absorber has a peak absorption as great as the quoted value for the Swiss P.T.T. absorber and a bandwidth many times as great. The building-board panel absorber (c) has a bandwidth comparable with that of a membrane absorber but a much smaller peak absorption.

After the work described had been completed, Dr. von Braunmühl pointed out in discussion that the weights used by him in his original experiments did not form approximate point loading masses as those used by the Swiss P.T.T. and subsequently by the author but were instead flat slabs of concrete covering an appreciable area of the building-board panel and bolted to it at the four corners. Such an arrangement would behave in some respects differently from the type used in the present experiments and would vary quite considerably according to the relative size of plate and panel and the method of fixing. Some tests were made using a steel weight of dimensions 7 in. × 9 in. (18 cm × 23 cm) bolted to the centre of a building-board panel 2 ft × 2 ft 6 in. (60 cm × 75 cm) but resonance in the simplest mode could still not be obtained.

4. CONCLUSIONS.

1. The absorbers tested in this laboratory give results very different from those published and the mode of action does not appear to be as postulated. It is not possible to vary the resonance frequency by changing the weights on the centre of the panel since the weights do not vibrate at these frequencies.

2. The resonance frequency of these building-board absorbers, as for the membrane absorbers, must be adjusted by varying the depth of the air-space. The membrane units, however, prove more amenable to calculation and the effective vibrating mass can be varied by using single or double sheets of roofing felt.

3. The peak absorption obtained with the building-board panel resonators is less than with the roofing felt units.

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